RESEARCH ARTICLE

Determining the Most Probable Orientation of a Part using Centroid Solid Angle Method

*M Suresh1, N Nisaantha Kumar2
1 Associate Professor, Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu, India - 641008.
2 Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu, India - 641008.

Received-11 November 2015, Revised-20 November 2015, Accepted-21 December 2015, Published-21 December 2015

ABSTRACT

In the current era, the rapid proliferation of automobiles has indeed led to a tremendous competition among the automotive companies and the only pathway to reach the culmination is through innovation. Innovation has long been a catalyst of growth and hence these industries are necessitating enhancement in their performance by systematically leveraging technology to facilitate innovation, with intent to offer world class quality products and services in a quicker phase. The result of such an innovation is the part feeder systems that are utilized in automated automotive assembly lines to segregate and position parts prior to packaging. Obtaining the favorable orientation of a part in assembly stations, within the stipulated time at disposal, is quite a tedious task to carry out. To overcome this problem, part feeding system is utilized, where it brings about the segregation and orientation of parts, before passing to assembly. A part feeder is a system in which the parts enter the feeder in random orientations and exit the system in a single specified (favorable) orientation. Having said, our work involves the determining of the most favorable orientation at which a part should align and orient itself before entering the assembly line and this determination is made using the centroid solid angle method. Brake pad being an irregularly shaped component and the component which faces critical orientation issues in automotive assembly units, is taken to be as our specimen for consideration in this work. Thus based on the most probable orientation of a part that we find using centroid solid angle method, an appropriate part feeder system could be designed.

Keywords: Brake pad, Centroid, Part feeders, Probable orientation, Solid angle, Assembly automation.

1. INTRODUCTION

Automation has become an essential element in various industries and is hence required in a large quantity. Owing to this, the industries have to come up with innovative automation systems to meet all the demands. An example for such system is a part feeding system. The part feeding system is very important for such products which help in reducing the lead time to meet the necessity. In manufacturing environment, automation is mainly used in the field of part handling and orienting a part in a desired orientation. Part feeders are used to change the possible orientation into probable orientation and retain the obtained orientation. Based on the part shape and orientation, the part feeding system is developed to feed, orient and store them. A brake pad which is an irregular component has been considered in this work.

Initially, the backing plate of the brake pad is stamped. After the stamping process, the surface of backing plate is roughened to increase adhesion to avoid material breaking away from the backing plate. Then adhesive is applied to the backing plate and the plate is prepared to bond with the friction materials. Raw materials are formulated for highest quality for better performance and long life. Materials are blended to obtain the best...
formulations so that the performance of the brake pad is improved. Then the unique formulations are molded under extreme temperatures and pressure into the shape of bricks. After the molding process, the friction materials are bonded to the backing plate under immense heat and pressure. Then the pads are heated again in the heating processor for 8 to 10 hours to attain everlasting attachment. Painting embellishes the appearance of the brake pads and protects them from rust and corrosion. After the molding process the brake pads are oriented and stored manually, which consumes more labour time. So a part feeding system is introduced in-between the molding and bonding process. Because of the part feeding system, productivity can be increased by reducing the labour time. The asymmetric part like brake pad has more number of orientations. This makes the process of feeding, orienting and storing a tedious task. Hence, a specialized feeding system has to be designed. An attempt was made by [1] to find the most probable natural resting orientation of a brake pad using drop test and theoretical methods. [2] described a new approach for analyzing the natural resting behavior of a non-rotational component. The method employs the energy envelope concept to analyze the natural resting of a component. [3] described the use of dynamic simulation to expedite the design and prototyping of parts feeders. Probabilistic descriptions of vibratory parts feeding behaviors are given and a comparison between simulated design experiments and physical experiments were done using a real industrial vibratory bowl feeder to show strong similarities between the results of the two types of experiments. An attempt was made by [4], to verify the existing hypotheses, which predicted the natural resting aspects of small engineering parts on soft and hard surfaces. [5] presented a description of typical assembly systems including manual, special-purpose automatic and programmable assembly systems. For each case, mathematical models were developed to describe the economic performance.

[6] applied centroid solid angle method to predict the probability of feasible natural resting aspects of curved surface objects. The theoretical values were compared and found to have a deviation of 2.6% to the empirical results. [7] predicted the natural resting behavior of a square prism and a rectangular prism on a hard surface. The method presented here is the centroid angle concept which assumes that the probability of any surface of a part on which it comes to rest, is directly proportional to the difference between the centroid solid angle of that aspect and the average of the critical solid angles of the neighboring aspects and inversely proportional to the height of the centre of gravity of that aspect. The results showed that the predicted data agree well with both the experimental data obtained. This is the first successful attempt that an analysis of the natural behavior of a part on a hard surface is done (without resorting to empirical factors).

2. CENTROID SOLID ANGLE METHOD (CSA)

A solid angle is defined as being of one steradian unit subtended by portion of a spherical surface whose area is equal to the square of the radius of the sphere [6]. A brake pad which is an irregular component has been considered in this work (shown in figure 1). The disproportionate part like brake pad has multifarious orientations. However, prioritizing the favorable orientations of the part, major 3 disparate orientations are taken to consideration for determining the most favorable orientation of the part. These orientations are shown in figure 2.
In this case, figure 3 depicts the surface area and the radius (R). For orientation ‘a’, the vertices of the projected surface are connected to the center of gravity in order to create a prism-like appearance as shown in figure B1, where the center of gravity of the brake pad is taken to be the center and a sphere is constructed with an arbitrary radius. The volume generated by the intersection of the prism and the sphere provides the expected volume. The centroid solid angle is then computed by the equation (2.1).

\[ W_i = \frac{\text{Surface Area}}{R^2} \]  

The Centroid Solid Angle (CSA) method is based on the simple assumption that the probability of a part resting on a particular resting orientation is proportional to the centroid solid angle. To elaborate, this method is based on the hypothesis that the probability for a part resting in a particular resting orientation is directly proportional to the solid angle or solid angle ratio subtended by the centroid to that surface and inversely proportional to the height of the centroid from that resting orientation. The generalized equation, as proposed by [7, 8] is shown in equation (2.2). In this way, probabilities of all orientations of the brake pad are calculated and discussed in detail under section 3.

\[ P_i = \frac{W_i / h_i}{\sum_{j=1}^{n} w_j / h_j} \]  

Where, 

\( P_i \) is the probability of having orientation ‘i’ for the resting part, 

\( W_i \) is the centroid solid angle traced by the orientation ‘i’ with respect to the centroid (steradian), 

\( h_i \) is the height of the orientation ‘i’ from the centre of gravity (mm)

### 3. RESULTS AND DISCUSSIONS

For determining the most appropriate and favorable orientation of brake pad, centroid solid angle method is used as discussed in section 2. The outcome of centroid solid angle method is discussed in detail in this section. Figure B1 shows surface area and is calculated using solid works 2010 software.

Figure B1 shows the contact surface area of a sphere when brake pad was in ‘a’ orientation. Surface area of ‘a’ orientation is calculated by mass properties option from solid works software. In order to justify the surface area on ‘a’ orientation with center of gravity of brake pad as center, a sphere is constructed with arbitrary radius. The intersection of prism and sphere is the expected volume. The same procedure is followed for ‘b’ and ‘c’ orientation (see figure B2 and figure B3).

After finding the surface area and height of each orientation, equation (2.2) is used for finding the probability of each orientation.

For orientation ‘a’, 

Surface area= 1.88 mm² 

Radius of sphere= 2 mm 

Centroid solid angle = Surface area / Radius² 

\( W_i = 1.88 / 4 = 0.47 \) steradian 

Centroid solid angle / height, for orientation ‘a’ = 0.47 / 25.929 = 0.0181 sr/mm 

Centroid solid angle / height, for orientation ‘b’ = 4.695 / 2.705 = 1.7358 sr/mm 

Centroid solid angle / height, for orientation ‘c’ = 0.8131 / 62.187 = 0.01307 sr/mm 

Probability for orientation ‘a’=0.0181/ (0.0181+1.7358+0.01307) = 0.010248 

Similarly the probability for orientations ‘b’ and ‘c’ was found and tabulated in table B1.

Table A1 shows that the probability of each orientation obtained through calculations as discussed above. Probability of orientation ‘b’ is 0.9828. This probability is high compared to the probabilities of other orientations. Thus, this brings the inference that the orientation ‘b’ is the most pertinent orientation of the part.
It is evident from figure 4, that the orientation ‘b’ has highest probability compared to orientation ‘a’ and orientation ‘c’. From this centroid solid angle method, it can thereby be asserted that among the three orientations taken into consideration, orientation ‘b’ is the most favorable orientation of the part and it can be inferred that a part feeding system could be designed based on the ‘b’ orientation.

Figure 4. Outcome of the CSA method

4. CONCLUSION

This work lucidly and comprehensively elucidates the probability variation among the three favorable disparate part orientations, through centroid solid angle method. In this study, the probability for orientation ‘b’ being 0.9828 can clearly be seen to be higher than the other two orientations ‘a’ (0.01024) and ‘c’ (0.00740). Thereby it is concluded from the centroid solid angle method that among the three disparate orientations taken into consideration, the orientation ‘b’ is the most apposite and favorable orientation. Thus, in this paper the most favorable orientation of a part with intricate geometries viz, brake pad is implied. This will enable the brake pad manufacturing industry for designing efficient part feeding systems for assembly lines thereby attenuating lead time and superfluous cost.

REFERENCES


## APPENDIX A

Table A1. Result of centroid solid angle method

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Surface Area (mm$^2$)</th>
<th>Radius (R) in mm</th>
<th>Centroid solid angle = Surface area / R$^2$ (steradian)</th>
<th>Height in mm</th>
<th>Centroid solid angle / Height (mm)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1.88</td>
<td>2</td>
<td>0.47</td>
<td>25.929</td>
<td>0.0181</td>
<td>0.01024</td>
</tr>
<tr>
<td>b</td>
<td>14.38</td>
<td>1.75</td>
<td>4.695</td>
<td>2.705</td>
<td>1.7358</td>
<td>0.9828</td>
</tr>
<tr>
<td>c</td>
<td>2.49</td>
<td>1.75</td>
<td>0.8131</td>
<td>62.187</td>
<td>0.01307</td>
<td>0.00740</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>1.76697</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

Figure B1. Surface area for ‘a’ orientation

Figure B2. Surface area for ‘b’ orientation
Figure B3. Surface area for ‘c’ orientation